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CAN SCIENCE EXPLAIN LIFE?

C. F. KRAFFT

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CAN SCIENCE EXPLAIN LIFE?

By
CARL F. KRAFFT
WASHINGTON, D. C.

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from the Author*

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FOREWORD

The purpose of the present work is to furnish a satisfactory mechanistic explanation for the fundamental life processes, especially in so far as they differ from known physical and chemical processes. The inability of scientists to explain how a complex living organism can reproduce itself through the medium of a single germ cell has caused many of them, even until the present day, to desert the mechanistic school and to return, reluctantly, to vitalistic teachings. Although the author's sympathies have always been with the mechanists, yet after candid and impartial consideration of this subject he has come to the conclusion that the arguments of the vitalists cannot be successfully answered on the basis of our previous scientific knowledge, and that the fundamental life processes have heretofore remained unexplained. Mere analogies do not constitute explanations, nor is the explanation of certain minor details equivalent to an explanation of fundamentals.

The spirazine hypothesis was conceived in December, 1925. During the year 1926 every possible effort was made to obtain publication of it in the scientific magazines, but without success. In some cases the article was returned without

any comments whatever, which may have been an expeditious but not a very honorable method of executing the duties which attach themselves to the office of editorship. In those cases where the editors did give it any sort of serious consideration it was condemned as being "unscientific" and "contrary to known facts," and was characterized as being only one out of many other "equally good guesses," although the author has not yet received from the critics thereof a single suggestion as to what some of those other equally good guesses might be. In still other cases it was returned with certain evasive excuses, as for example that it was "too technical," although the real reason was probably that the author was not sufficiently noted.

After the prospects of obtaining publication through the usual channels seemed hopeless, a number of mimeographed pamphlets setting forth the salient features of this hypothesis were prepared and distributed among those who were known to be interested. An abstract notice of them was recorded in Chemical Abstracts, 22, 2584 (July 20, 1928).

The present work is a revision of the author's earlier book on "Spirazines," published in the fall of 1930. An effort has been made to clarify some of the explanations, and a considerable amount of new material has been added.

CAN SCIENCE EXPLAIN LIFE?

INTRODUCTION

The various forms of life which are encountered in nature exhibit such a variety of appearances and such a profusion of details that the casual observer is often too bewildered by the complexity of his surroundings to gain a clear conception of life processes in their entirety and to distinguish what is fundamental and indispensable from what is superficial and unessential.

Life is usually recognized by specific bodily form, spontaneous mobility, and responsiveness to stimuli, but these characteristics can all be closely imitated artificially and in the lower forms of life are often entirely absent, so that they must be regarded as secondary characteristics which have developed in the course of evolution and not as primary attributes of life itself.

Every living organism is unique in that it constitutes an autonomous self-contained entity having its own specific behavior, and which is capable, under favorable conditions, of growing and producing others like itself. The phenomena of growth and reproduction are exhibited by every living organism regardless of its rank in the plant or animal kingdom and establish in nature a

sharp line of demarcation between living and non-living things. Although growth and reproduction, in their broadest aspect, amount to nothing more than self-duplication, yet they are fundamentally different from any of the other processes heretofore known to science.

Biological growth does not proceed in the same manner as the growth of crystals because extensive chemical transformations take place during the process of metabolism whereas the growth of crystals involves no permanent chemical change whatever. It also differs from crystal growth in that the assimilation of food by the cells of living organisms does not require saturated solutions such as are necessary for the growth of crystals. Another difference is in the final result produced, for although biological growth can produce organisms of the utmost complexity and variability and generally of rounded contour, yet crystal growth produces only such structures as are of angular contour, internally homogeneous, and neither complex nor variable.

Biological reproduction, or more specifically cell division, involves more than mere dispersion or subdivision because the progeny retain, either actually or potentially, not only the chemical composition but also the specific physical organization of the parent cell. Neither can cell division be

regarded as merely a form of dissociation because the progeny of living organisms are structurally similar to the parent, whereas the particles which result from chemical dissociation are always dissimilar from the undissociated molecules.

The ultimate cause of life, whether it be a certain substance or a specific detail of physical structure, must be the same for all living organisms because the specific differences which distinguish one living organism from another disappear as we go down the scale of plant or animal life. Since there are innumerable species of bacteria which exhibit no internal heterogeneity whatever, even under the most powerful magnification, it appears that the ultimate units of living matter must exist on a scale smaller than the limit of microscopic vision, which is about $1/50,000 \text{ cm} = 2,000 \text{ Angstrom units}$. Since the largest organic molecules which have been prepared synthetically measure about ten Angstrom units ($10 \times 10^{-8} \text{ cm}$) across, it is evident that the ultimate units of living matter must exist in a region where we come dangerously close to the details of chemical structure, and that the ultimate cause of life must be looked for in the realm of chemistry rather than in the realm of physics.

That the fundamental life processes must be due, either wholly or partly, to specific chemical

structures is generally admitted, but there is a prevailing opinion that the chemical configurations which are necessary for this purpose must be extremely complex. The failure of all previous efforts to devise some type of chemical structure which is capable of duplicating itself does not prove, however, that the solution of the problem must lie in the direction of extreme complexity. The complex chemical structures which make up the tissues of the higher plants and animals have developed gradually during the course of evolution, and the fact that they are necessary for the proper physiological functioning of the particular organisms in which they now occur does not prove that they were also the original cause of the incipient life processes in the most primitive submicroscopic forms of life from which these higher plants and animals have developed.

With the exception of certain plasmodia and syncytia which have no definite cell walls, the bodies of all higher plants and animals consist of aggregates of separate living cells, all of which are constituted according to the same general plan in that they all consist of an outer cytoplasm which may contain central bodies, asters, fibrillae, plastids, Golgi-bodies, etc., and an inner nucleus which may contain chromosomes, linin network, etc. Nucleated cells like those which form the

bodies of the higher plants and animals have a definite lower limit of size, being never smaller than several (approximately five) microns in diameter. (1 micron = $1/10,000$ cm = 10,000 Angstrom units.) Since the diameter of the benzene ring, as measured between the centers of the carbon atoms, is about three Angstrom units (3×10^{-8} cm) in diameter, it would require a series of about 17,000 benzene rings to extend across the smallest nucleated cell. It is probably safe to say that a structure of such complexity could never have sprung into existence spontaneously from inorganic substances. The conclusion is therefore inevitable that the typical nucleated cell does not represent the most primitive form of life, but is probably the final result of a long process of evolution.

A much more primitive form of life is exhibited by the bacteria which carry on the same processes of metabolism and pass through the same cycles of growth and cell division as their nucleated relatives so that they must be regarded as true living organisms. Bacteria differ from nucleated cells in that they are definitely smaller in size, are usually formed to resemble some simple geometric figure, do not contain distinct chromosomes, centrosomes, or other self-perpetuating

bodies, never conjugate, and never develop into multicellular organisms.

The existence of a definite gap in size between the smallest nucleated cells and the largest bacteria indicates that bacteria represent a distinctly different form of life from nucleated cells, and when we consider the extreme simplicity of their forms and the homogeneity of their internal structures we feel inclined to believe that they constitute the most primitive class of living organisms. Even the largest of them are not far above the limit of microscopic vision, and there is every reason to believe that there are innumerable species which are similar in form and constitution to their larger representatives, but which are too small for the microscope to reveal.

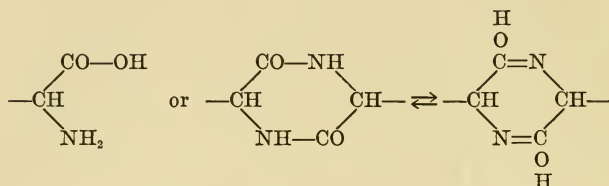
In order to avoid a confusion of issues at the outset, we shall for the present confine our attention as much as possible to the bacteria because these exhibit the fundamental life processes in their simplest phases. The problem of explaining life does not require that we should furnish an explanation of the entire process of evolution, but only of those processes and characteristics which are common to all forms of life and which must have been exhibited by the most primitive form of living matter as it first appeared on this earth.

THE CHEMICAL BASIS OF LIFE

There being no evidence to justify us in assuming that life processes are due, primarily, either to specific details of physical structure or to extreme complications of molecular structure, we find ourselves driven to the conclusion that life processes must be due to some comparatively simple principle of chemistry which has not yet been discovered. To find a clue to this we must investigate the chemical structure of proteins, because protoplasmic materials which are principally of protein constitution appear to constitute the basis of all life processes. Fats and carbohydrates, although formed during protein metabolism, are evidently nothing more than by-products which may be useful at times for fuel or skeletal support and may by their presence exert the most profound effects upon the behavior of the surrounding protoplasmic materials but are not chemically constituted in such a manner that they can grow or reproduce.

All proteins decompose hydrolytically upon prolonged boiling with hydrochloric or sulphuric acid or with alkalis, upon treatment with superheated steam, or upon treatment with certain enzymes such as pepsin or trypsin, and yield as their principal cleavage products a mixture of

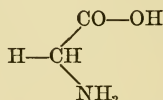
amino acids or their anhydrides (diketopiperazines), which may be represented generally as follows:



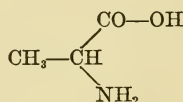
About thirty of these amino acids or their anhydrides have been isolated, the structural formulas of the more important ones being as follows:

Aliphatic monobasic monamino acids:

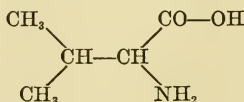
Glycine



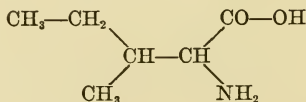
Alanine



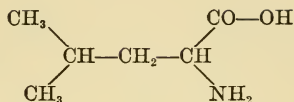
Valine



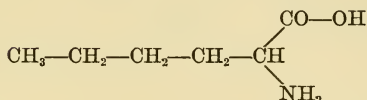
Isoleucine



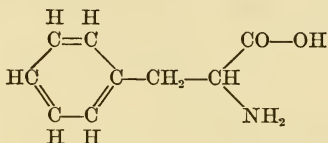
Leucine



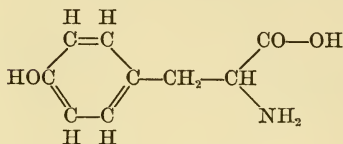
Caprine

*Aromatic monobasic monamino acids:*

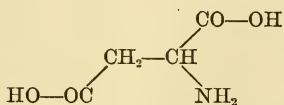
Phenylalanine



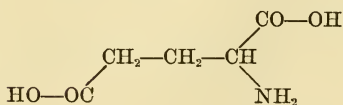
Tyrosine

*Dibasic monamino acids:*

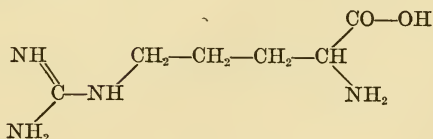
Aspartic acid

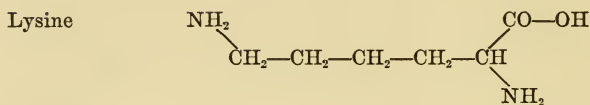
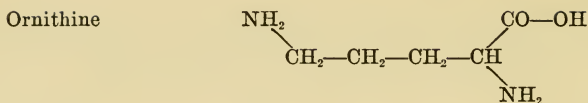


Glutamic acid

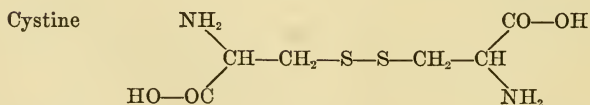
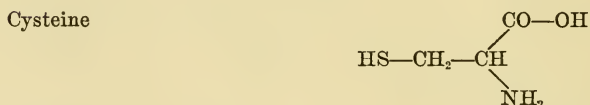
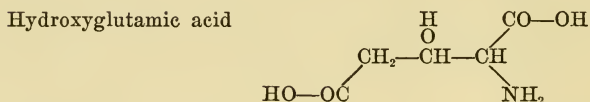
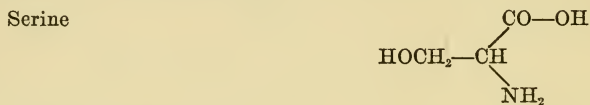
*Monobasic diamino acids:*

Arginine

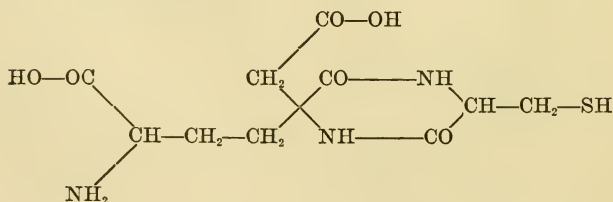




Hydroxy- and Thio-amino acids:

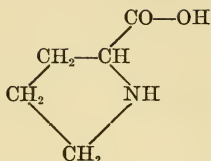


Glutathione (γ -glutamylcysteylglycine)

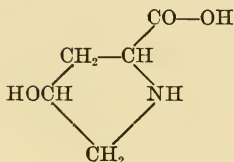


Heterocyclic amino acids:

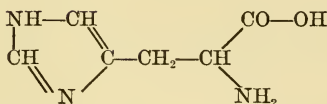
Proline



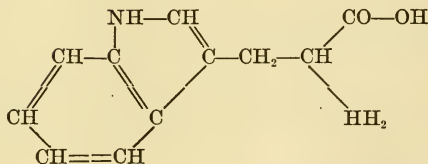
Hydroxyproline



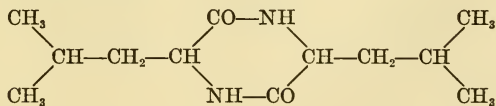
Histidine



Tryptophane

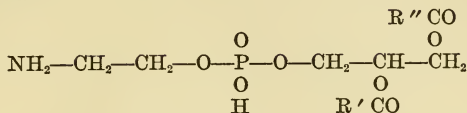
*Anhydrides:*

Leucine anhydride



Because of their frequent occurrence in living tissues, the formulas of the following substances should also be given.

Kephalin



APPROXIMATE PERCENTAGE YIELD OF AMINO ACIDS FROM PROTEINS

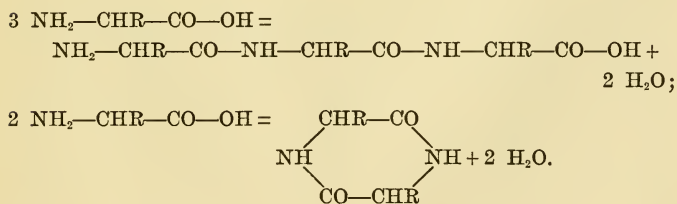
	Egg Albumin	Ca- sein	Edes- tin	Fi- brin	Gela- tin	Glia- din	Hemo- globin
Glycine	0.0	0.5	3.8	3.0	26.0	0.02	0.0
Alanine	8.1	1.5	3.6	3.6	8.7	2.0	4.2
Valine	2.5	7.0	6.2	1.0		0.2	
Isoleucine		1.4					
	11.0		21.0	15.0	7.1	5.6	30.0
Leucine		7.9					
Phenylalanine ...	5.1	3.9	3.1	2.5	1.4	2.4	4.2
Tyrosine	1.8	5.0	2.1	3.5	0.01	1.2	1.3
Aspartic acid.....	2.2	1.4	4.5	2.0	3.4	0.58	4.4
Glutamic acid...	9.1	15.8	19.0	10.0	5.8	37.0	1.7
Arginine	4.9	4.5	15.0	4.7	8.2	3.2	5.4
Lysine	3.8	6.0	2.0	11.0	5.9	0.0	4.3
Serine	0.0	0.4	0.3	0.8	0.4	0.13	0.6
Cystine	0.3	0.02	1.0	1.2		0.45	0.3
Proline	3.6	7.0	4.1	3.6	9.5	7.1	2.3
Hydroxyproline		0.2	2.0		14.0		1.0
Histidine	1.2	3.0	2.0	6.4	0.9	0.61	11.0
Tryptophane	+	1.5	0.4	1.3		+	+

The accompanying table gives the percentage yields of the various amino acids from certain proteins, but these values should be interpreted

cautiously because it has never been proved that amino acid molecules exist as such in proteins, even in peptide combination. As will be explained in the subsequent chapters, they probably originated as torn-off fragments which became dislodged from the fabricated protein structure during hydrolysis, and whether the dislodged fragments are of one size or another may depend not only on the chemical structure of the protein but also on the nature of the hydrolyzing agent. There is, in fact, only very little justification for employing the molecular concept at all in our consideration of proteins. The molecular theory was invented for the explanation of the definite and sometimes simple proportions by weight or volume in which certain substances react, but the experiments on which the molecular theory were based did not include experiments with proteins, the combining proportions of which are neither definite nor simple. Those proteins which are soluble in water may consist, not of particles, but of fibrous networks as is evidenced by the opalescence and stringyness of their solutions and by many of their other physical and chemical properties, whereas those which required special reagents to dissolve them were probably transformed chemically during the process, so that

they are no longer identical with the substances which exist in living cells. The vulnerability of proteins to even the most gentle chemical treatment is well illustrated by the treatment of hair for a short time with dilute hot sodium carbonate solution, which will reduce the cystine yield from about three percent to almost nothing. If an individual fiber of protein can be called a "molecule" merely because it represents the smallest state of subdivision in which that substance exists in nature, then it appears that a single fiber of cotton should also be called a "molecule."

By suitable chemical treatment the above-mentioned amino acids can be condensed, with the elimination of water, to form either chain structures known as polypeptides or ring structures known as diketopiperazines:



Numerous methods for preparing polypeptides have been devised by Emil Fischer and his col-

laborators in Germany, and molecules containing as many as nineteen amino acid groups have been prepared.

There is an abundance of evidence that the peptide linking —CO—NH— occurs in the protein materials of all living cells. For example, the same pink or violet color (the biuret reaction), which is produced from this linking in any of the higher polypeptides by the addition of an excess of sodium hydroxide and a trace of copper sulphate is also produced upon the addition of these reagents to proteins. Polypeptides and proteins also produce the same amino acids when heated with mineral acids or alkalies, so that they must contain the same structural units. That the amino acid groups in proteins are connected by means of peptide linkings is also evidenced by the fact that all proteins which have not been previously treated with mineral acids or alkalies form neutral solutions, so that the number of free carboxyl groups must be equal to the number of free amino groups. The fact that only a small fraction (usually less than ten percent), of the total protein nitrogen can be separated as free amino nitrogen shows that most of the amino groups of the original amino acid molecules must have become modified or occupied in some manner at the time when

these amino acids were assimilated by the protoplasmic materials, and it is inconceivable how the removal from the field of action of exactly equal numbers of amino and carboxyl groups could be explained in any other manner than by the formation of peptide linkings.

From considerations such as these the conclusion has generally been reached that the protoplasmic materials of living cells grow by the formation of peptide linkings with amino acid molecules, so as to produce either the chain structure of polypeptides or the ring structure of diketopiperazines. It was formerly thought that the structure thus produced was entirely of polypeptide nature, but more recent investigations have shown that diketopiperazines are always present among the hydrolytic cleavage products of proteins, even under conditions which would render their synthetic formation from the initially produced polypeptides highly improbable. However, the chemical structures of the solid or colloidal protoplasmic materials which have been subjected to hydrolysis may not be identical with the molecular structures of synthetically prepared polypeptides, even though they may both contain peptide linkings, and with our present scanty knowledge of protein structure we would not be

justified in assuming, without further proof, that this difference in chemical structure between proteins and polypeptides would not be sufficient to explain the subsequent formation of diketopiperazines when proteins are subjected to hydrolysis. That diketopiperazines are not normally present in most proteins is also evidenced by the fact that neither pepsin, tripsin, nor erepsin will split the diketopiperazine ring.

But regardless of whether or not the diketopiperazine ring is present in proteins, it appears, from biological considerations, that neither the simple polypeptide structure nor the unaltered diketopiperazine rings are adequate for the purpose, either singly or in juxtaposition. Neither of these structures shows any tendency to grow spontaneously by assimilation of amino acid molecules, or to divide spontaneously into daughter structures which either possess or acquire the same specific structural organization as the parent. The persistence with which living organisms will devour every bit of food material within reach and invade the entire earth's surface with their progeny shows that they must possess within the chemical structures of their tissues some contrivance which is definitely superior to ordinary chemical forces and which can function in a man-

ner unknown to chemical science. What is needed for this purpose is not some new form of molecule but some new type of chemical structure; not some new arrangement, but some new principle of atomic behavior.

SPIRAZINES

One of the most remarkable characteristics of living organisms is that all normal physiological functions can take place while growth is in progress. In this respect living organisms differ from artificial contrivances, which usually cannot perform their intended functions while they are in the process of construction. Regardless of whether we are considering a multicellular or a unicellular organism, its physical behavior does not seem to bear any direct relationship to the chemical activity of the growing protoplasmic materials of which it is composed. This peculiar independence of behavior and growth can be explained only on the theory that the specific structural characteristics of protoplasmic materials are not changed, either physically or chemically, by the addition of amino acid molecules thereto.

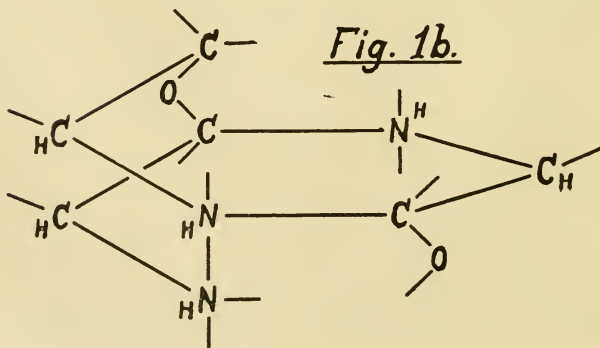
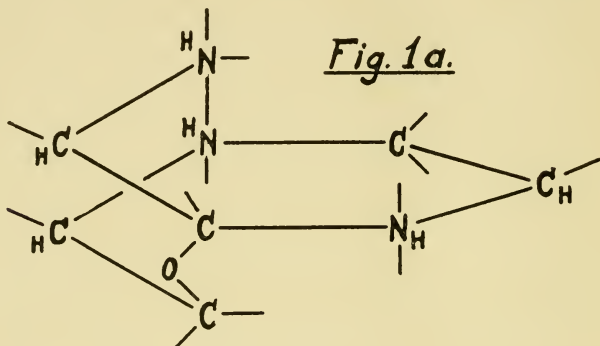
If the protoplasmic structures of living cells were built up of discrete molecules of utmost complexity, as is generally supposed, then it would be impossible to explain the process of growth which in nature takes place continuously and spontaneously by the assimilation of one amino acid molecule after another. The synthesis of complex

molecules can never be accomplished by one continuous process, but even if it could be thus accomplished there would have to be an abrupt change in the nature of the process after the completion of one molecule in order to initiate the formation of the next one.

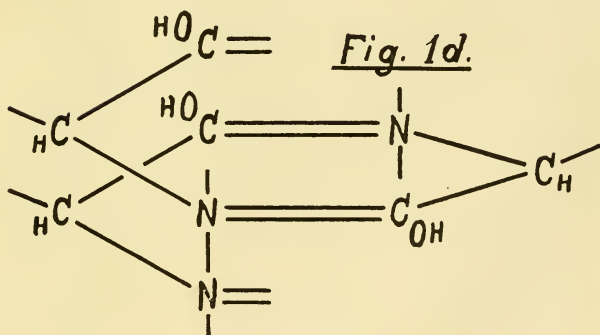
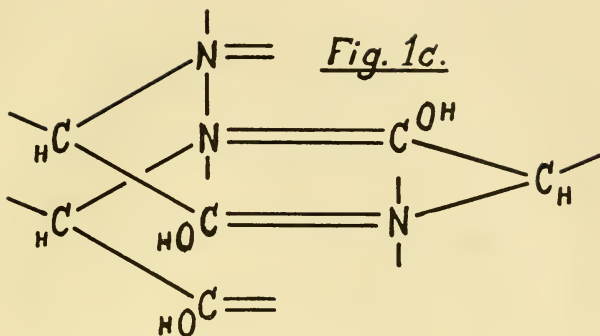
However, there is no experimental evidence that the protoplasmic structures of living cells are built up of discrete molecules, or that they are of utmost chemical complexity. In regard to their supposed molecular constitution, it might be stated that most proteins, and especially those which form the nuclear or actively growing portions of living cells, require special chemical treatment to bring them into solution, whereas those which will dissolve in water, as for example the albumins, are probably no longer integral portions of the cell structure but may consist of free colloidal bodies which have grown out from the nuclear material and have become detached. In regard to their supposed chemical complexity, a distinction should be made between two-dimensional complexity and three-dimensional complexity. Although it seems impossible to explain growth and reproduction if we assume that protoplasmic materials possess three-dimensional complexity, yet it seems comparatively easy to explain these processes if we assume that they

possess only two-dimensional complexity and that the third dimension is built up by mere superposition of layers having the same arrangement of atoms.

Growth and reproduction being the two indispensable processes without which life is incon-



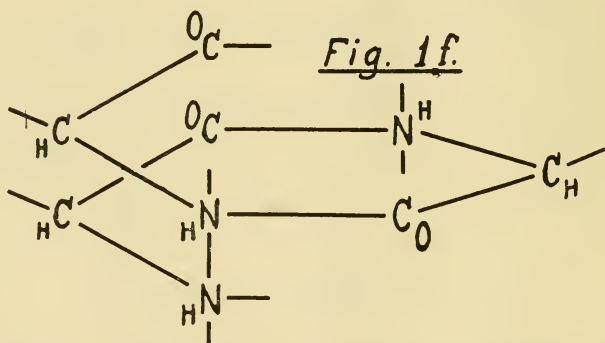
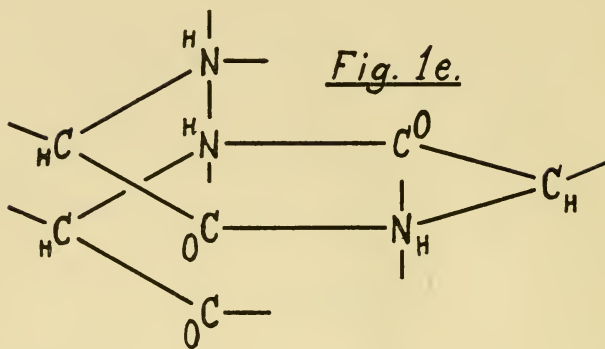
Enol-Form of Spirazine



ceivable, the chemical structure of living matter from which such life processes seem to originate must possess the two following characteristics:

(1) It must be of such a nature that the process of growth by the formation of peptide linkings with amino acid molecules can take place con-

Keto-Form of Spirazine



tinuously without producing any abrupt change in its external chemical configuration; and

(2) It must be capable of division into a plurality of portions each of which retains either actually or potentially the complete pattern of the original structure.

Of the various geometric forms which chemical structures might exhibit, the helical spiral appears to be about the only one which possesses characteristics similar to those mentioned above, and it appears that the helical spiral is also the only configuration, besides rings and chains, which the polypeptide molecule can be made to assume. The ease with which diketopiperazine rings are formed from dipeptides, and the difficulty of splitting such rings, seems to indicate that the valencies of the successive carbon and nitrogen atoms in dipeptides are at such angles to one another as to give them a natural tendency to form six-atom rings; and if dipeptides tend to form six-atom rings, then polypeptides would tend to form spirals with six-atom convolutions, which will be referred to, briefly, as "spirazines."

It will be observed that one of the valencies of the alpha carbon atom in these amino acids is always occupied by hydrogen. Chemically it would be possible to attach more complex groups in this position, but it will be found upon experimentation with atomic models that the presence of more complex groups in this position would render the spirazine structure impossible, and it will be observed that complex groups never occur in this position in the decomposition products of natural proteins.

The two ends of such a spirazine will be different in that one end will be formed of an acid carboxyl group whereas the other end will be formed of a basic amino group. When the dissimilarity of chemical structure at the two ends is taken into consideration, it seems highly improbable that the ability to grow by assimilation of amino acid molecules could be possessed by both ends alike. The fact that the physiological effects of different substances when injected into the blood stream are due almost entirely to the positive kations seems to indicate that assimilation in animal cells takes place at the carboxyl ends only, although the acid character of the chemically active portions of living matter may also be due to phosphoric acid radicles clinging to the amino groups at either end of the spirazine, and acting catalytically as intermediaries to facilitate the assimilation of amino acid molecules, just like sulphuric acid acts catalytically to facilitate the combination of alcohols with organic acids to form esters. The fact that phosphorus occurs principally in the nuclear materials where such assimilation is known to take place, and even there only in comparatively small amounts, seems to indicate that it does not enter permanently into the interior of the chemical structure of proto-

plasmic materials but is associated only with the actively growing portions thereof.

The successive nitrogen atoms along each side of the spirazine will increase the basicity of the terminal nitrogen atom, just like the two nitrogen atoms in diazo compounds increase the basicity of each other. Similarly the carbonyl groups along each side of the spiral will increase the acidity of the terminal carbonyl group. We thus have a strongly basic group held firmly in close proximity to a strongly acid group without being permitted to neutralize the same, which may account for the remarkable ability of living matter or its enzymes to digest all sorts of complex food materials and to appropriate the resulting substances spontaneously and continuously for the building up of its own protoplasmic structures.

If the successive nitrogen atoms in a spirazine are joined to one another by means of their fourth and fifth valencies in the manner shown, which seems to be entirely possible by reason of the fact that these valencies in amino compounds are always of opposite sign, then it appears that at least some of the nitrogen atoms in proteins are really pentavalent and should therefore be incapable of forming hydrochlorides in stoichiometric proportions as in the case of polypeptides. This is in complete agreement with experimental

facts, for it has been found that the amounts of hydrogen chloride gas which are taken up by proteins are much smaller than the amounts which they should take up if they were ordinary polypeptide structures.

On the other hand, the amount of acid which a protein is capable of neutralizing is always much greater than the amount which could be taken up by the terminal —NH_2 groups, which never contain more than about ten percent of the total protein nitrogen. Similarly the amount of base which a protein is capable of neutralizing is always much greater than the amount which could be taken up by the terminal —CO—OH groups, assuming these to be about equal in number to the —NH_2 groups. It must therefore be concluded that the ability of proteins to neutralize acids and bases is due not only to the terminal amino and carboxyl groups, but also, in a large measure, to the peptide groups —CO—NH— along the sides of the spirazines.

In the spirazine structure shown in Figs. 1a and 1b, the alternate peptide groups are connected to one another by means of the fourth and fifth valencies of the nitrogen atoms, and also by means of the oxygen atoms, but these connections are probably not very permanent and may change over into the enol-form shown in Figs. 1c and 1d,

or into the keto-form shown in Figs. 1e and 1f. It would probably not be possible for acid or basic radicals to attach themselves to the sides of the spirazines and become neutralized while the configuration shown in Figs. 1a and 1b exists, but such neutralization should be possible as soon as the structure changes over to the configurations shown in Figs. 1c, 1d, 1e, or 1f. The relation of these tautomeric changes to the chemical and physical behavior of protoplasmic materials offers a promising field for further speculation, but cannot be taken up in detail in the present brief discussion of this subject.

Life probably commenced with the spontaneous formation of di- and tri-peptides from inorganic substances. The process may have commenced with the spontaneous formation, at high temperatures, of small quantities of acetylene $\text{CH} \equiv \text{CH}$. Unsaturated compounds of this sort will readily form addition products and may have produced glycine or other amino acids. For example, the acetylene may have combined with water in the presence of dilute sulphuric acid to form acetaldehyde $\text{CH}_3 \cdot \text{CHO}$, and the acetaldehyde may have polymerized into aldol $\text{CH}_3 \cdot \text{CHOH} \cdot \text{CH}_2\text{CHO}$ which will also occur spontaneously at ordinary temperatures in the presence of dilute

acids or salts. At higher temperatures the aldol may have been converted into crotonaldehyde $\text{CH}_3 \cdot \text{CH} : \text{CH} \cdot \text{CHO}$ by the loss of a molecule of water and the latter may have become oxidized to crotonic acid $\text{CH}_3\text{CH} : \text{CH} \cdot \text{COOH}$. Since crotonic acid contains a double bond, it could easily have been converted into the corresponding amino acid $\text{CH}_3 \cdot \text{CH}_2 \cdot \text{CHNH}_2 \cdot \text{COOH}$ either by direct addition of ammonia or by combination with some oxide or acid of nitrogen and subsequent reduction. The amino acid molecules may then have been converted into polypeptides by the action of dry heat, and the latter, under suitable conditions, may have formed the first spirazines.

The individual spirazines thus produced may then have developed into more complex structures by folding over upon themselves as will be described more in detail later. Endwise growth of such structures may then have taken place either by assimilation of complete amino acid molecules which may have been present in the surrounding medium, or by the spontaneous synthesis of the alpha amino acid structure from the carbon dioxide, water, and nitrogen compounds in the surrounding medium, such synthesis having probably been effected by the catalytic action of the spirazines themselves in the presence of sunlight. Although there is no experimental evidence that

the evolutionary development of living matter actually began in the specific manner above suggested, nevertheless, it appears from the foregoing example that the spontaneous formation of spirazine structures from inorganic substances under conditions which actually existed in nature may be readily explained on the basis of known experimental facts.

The similarity in form and appearance of these primitive hypothetical structures to the various lower or elementary forms of life, such as the filamentous bacteria, connective tissue fibers, and nerve fibers, will be apparent. In each case the cross-sectional pattern will be the same at any point along the length and comprises not only the arrangement of the spirazines with respect to one another but also their directions of twist. This pattern will be characteristic of the species and upon transverse fission will be transmitted to the progeny.

The possession by the spirazine structure of a definite direction of twist will also account for the optical activity which is always exhibited by substances obtained from living organisms, and also for the partiality which is usually shown by living organisms towards one optical isomer over another. In living organisms chirality is the rule rather than the exception, and can be accounted

for only on the basis of an inherently twisted structure such as the spirazines possess.

It is an interesting fact that all proteins which have not been subjected to too severe chemical treatment will rotate the plane of polarization of light to the left. The fact that animal proteins have the same direction of rotation as vegetable proteins might be accounted for on the theory that since animals either feed upon plants directly, or upon other animals which do feed upon plants, it might be expected that the structural materials of plant and animal tissues would exhibit some features in common. It is not so easy, however, to explain why all plant proteins rotate the plane of polarization to the left, unless we are willing to admit that all the present species of plants have descended, not only from a single ancestral species, but also from a single spirazine. Such an assumption should not be summarily rejected as unreasonable unless we can find some other way of explaining the uniform optical properties of all proteins. If there would be only a few of them, it might be attributed to coincidence; but since the number of proteins whose optical properties have been determined runs into hundreds, the possibility of it being due to mere coincidence must be ruled out.

PROTOPLASMIC STRUCTURE

Since a single spirazine, being of about the diameter of a benzene ring, measures only about three Angstrom units (3×10^{-8} cm) between the centers of the atoms on opposite sides, it is evident that even the smallest bacteria, and all other fibrous forms of living matter which are visible under the microscope, must consist of aggregates of large numbers of spirazines. The large amounts of water which protoplasmic materials always contain, and the rounded forms which the simplest units of living matter always exhibit, seem to indicate that the spirazines thereof are not arranged in closely packed formation like the molecules of a crystal, but rather in some sort of open or spaced-apart formation.

Chemical union between adjacent spirazines can take place only through the amino, the carbonyl, or the alpha carbon groups, because these are the only groups that are present. Any two adjacent spirazines must therefore be connected, directly or indirectly, in one of the following ways:

- Amino nitrogen to amino nitrogen;
- Amino nitrogen to carbonyl carbon;
- Amino nitrogen to alpha carbon;

Carbonyl carbon to carbonyl carbon;
Carbonyl carbon to alpha carbon;
Alpha carbon to alpha carbon.

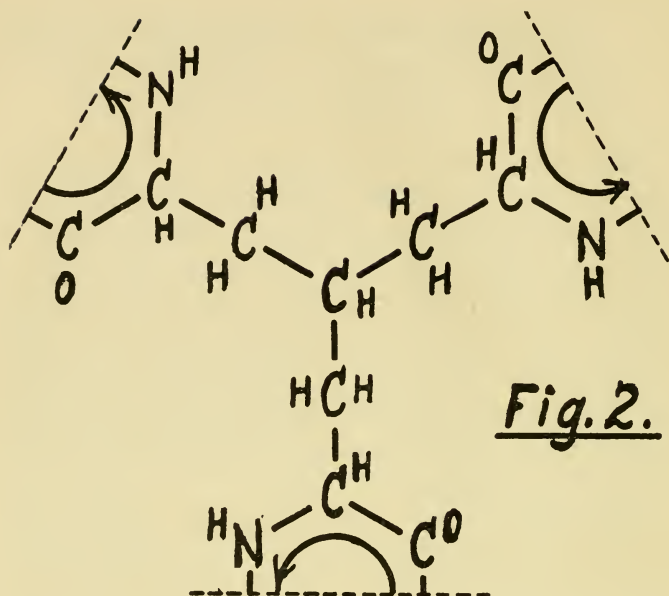
Any of the above unions, except those which involve direct connections between nitrogen and nitrogen or between nitrogen and oxygen, would be chemically stable, but their stability alone does not prove that they exist in nature. Protoplasmic materials have not resulted from a promiscuous mixture of the elements, but from an orderly and systematic process of evolution in which only those configurations have survived which have conformed to the dominating influence of the spirazines. It appears from the chemical structures of the various protoplasmic decomposition products that only the following unions between adjacent spirazines occur in nature:

- (1) Direct union of amino nitrogen to carbonyl carbon, as evidenced by the urea and guanidine complexes;
- (2) Direct union of alpha carbon to alpha carbon, as evidenced by aspartic acid (doubtful);
- (3) Indirect union of alpha carbon to alpha carbon by means of one, two, or three $\text{—CH}_2\text{—}$ groups, as evidenced by glutamic acid, arginine, and ornithine, respectively.

(4) Indirect union of alpha carbon to alpha carbon by means of the $\text{—CH}_2\text{—S—S—CH}_2\text{—}$ group, as evidenced by cystine.

The above conclusions were arrived at on the assumption that protein nitrogen occurs only in the spirazines. There is no evidence that it occurs anywhere else, and the amount of nitrogen that is present in the spirazines alone is too much rather than too little to satisfy the percentage composition of proteins as found experimentally. The two amino groups of arginine, ornithine, and lysine were therefore assumed to have come from adjacent spirazines.

The hydrocarbon side chains of amino acids exhibit frequent branching at the beta and gamma carbon atoms, as in the case of valine, isoleucine, leucine, phenylalanine, and tyrosine. Such branching, at first glance, suggests triple junctions between three adjacent spirazines as shown in Fig. 2. Such triple junctions would undoubtedly be chemically stable and will fit together nicely to form hexagonal compartments as shown in Fig. 3, which would probably be able to grow and perpetuate themselves if they actually existed. However, if such structures exist in nature, then the decomposition products of protoplasmic substances ought to contain tri-amino or tri-carboxylic acids or



A Triple Junction of the $\gamma\gamma\gamma$ -Type.

some derivatives thereof, whereas no such compounds have ever been found. It appears, therefore, that we would not be justified in assuming the extensive existence of triple junctions of this type, notwithstanding their adaptiveness for the building up of three-dimensional structures.

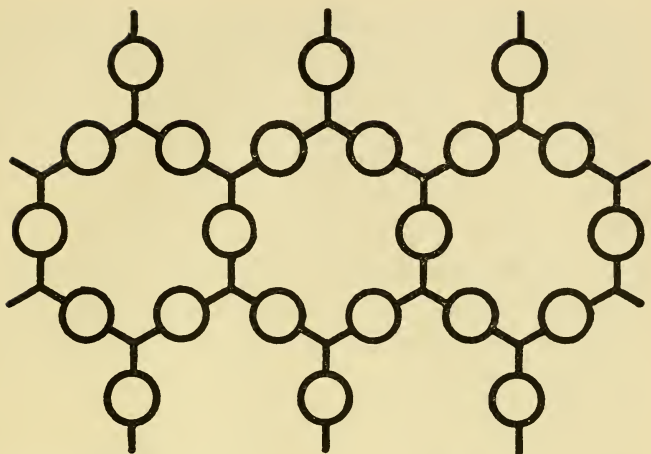


Fig. 3. *Hexagonal
Compartments*

The manner in which the adjacent spirazines of protoplasmic structures became connected to one another in nature must have been intimately related to the evolutionary development of living matter. The linking of adjacent spirazines with one another may have resulted either from polymerization of separate spirazines or from the folding over of the individual spirazines upon themselves. If it resulted from polymerization, then

combinations of right-handed and left-handed spirazines should have occurred frequently, and the number of optically right-handed combinations should have been about equal to the number of optically left-handed combinations. However, since nearly all proteins are left-handed, it must be concluded that the evolutionary development of protoplasmic structures could not have taken place by random polymerization but was probably brought about by some sort of folding over process.

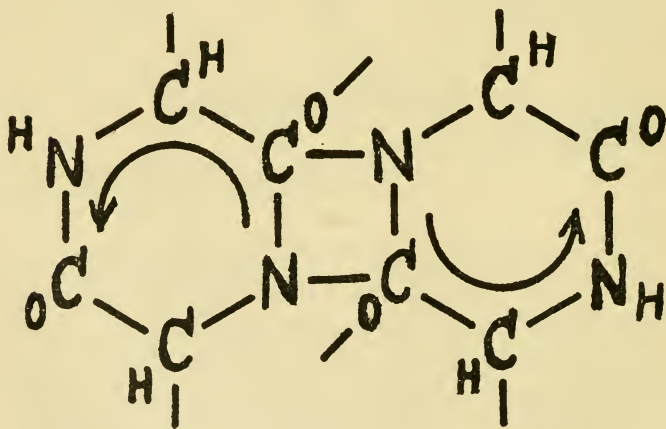


Fig. 4.

It might appear from diagrammatic illustrations on paper that when a spirazine folds over upon itself, the amino and carbonyl groups of the folded over portion would come directly opposite the carbonyl and amino groups, respectively, of the remaining portion, so that they would be likely to combine chemically as suggested in Fig. 4. It is doubtful, however, whether such a double union occurs in nature. The adjacent portions of the convolutions of two spirazines with the same direction of twist will always slope in opposite directions, which may render it difficult to bring the amino and carbonyl groups directly opposite each other along two different lines without considerable distortion of the spirazines themselves. Furthermore, the structure thus produced would constitute merely a flat sheet containing only a single layer of spirazines which would be incapable of forming three-dimensional structures.

It seems more likely that the folded-over portion will join the remaining portion along only a single line, so that a repetition of this process will produce the triplet shown in Fig. 5, and a continuation of the same process over a large area will produce the configuration of polygonal compartments shown in Fig. 6.

A group of three spirazines connected as shown in Fig. 5 may have constituted the most primitive

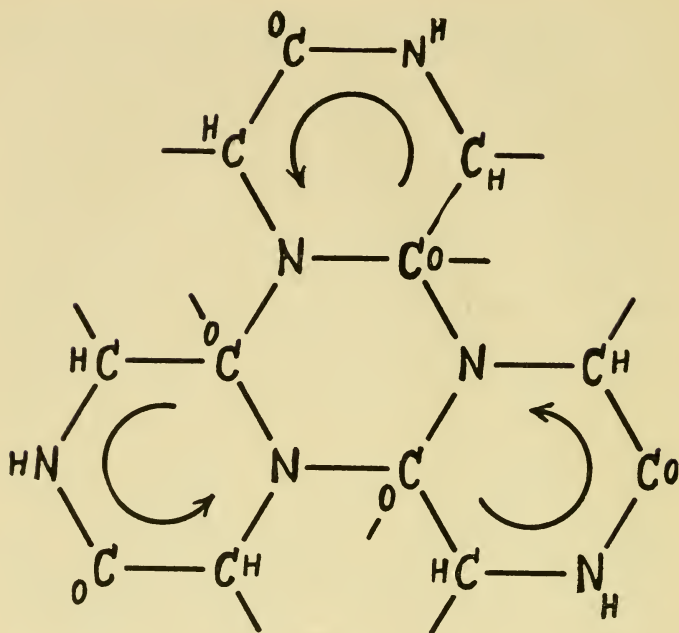


Fig. 5. *A Spirazine Triplet*

form of life, but it seems more likely that this configuration was only transitory and that the folding-over process continued until an organism of about the size shown in Fig. 7 was produced. Since a single polygonal compartment has a width of about ten Angstrom units (one millimi-

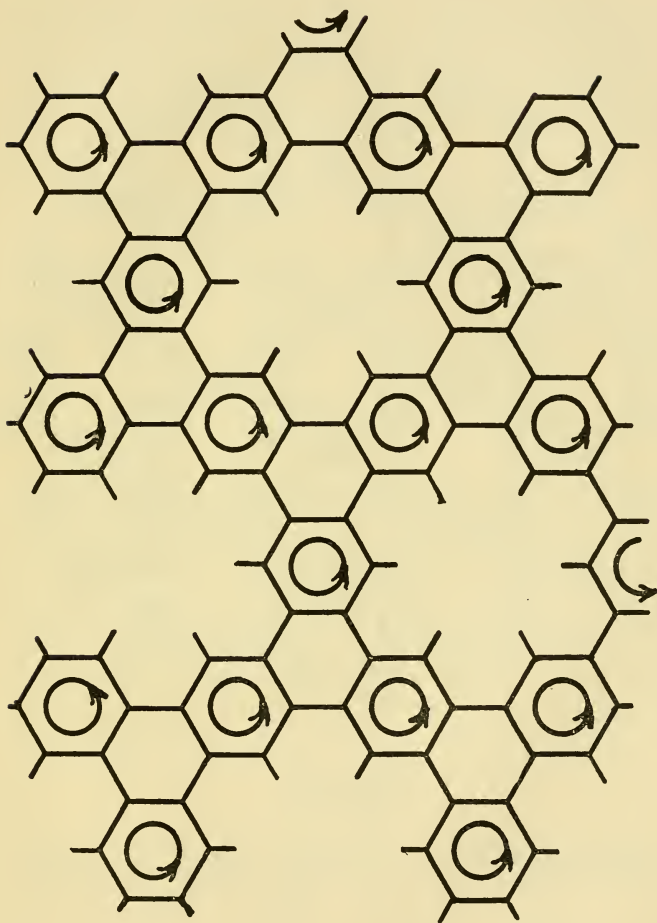


Fig. 6. *Polygonal Compartments.*

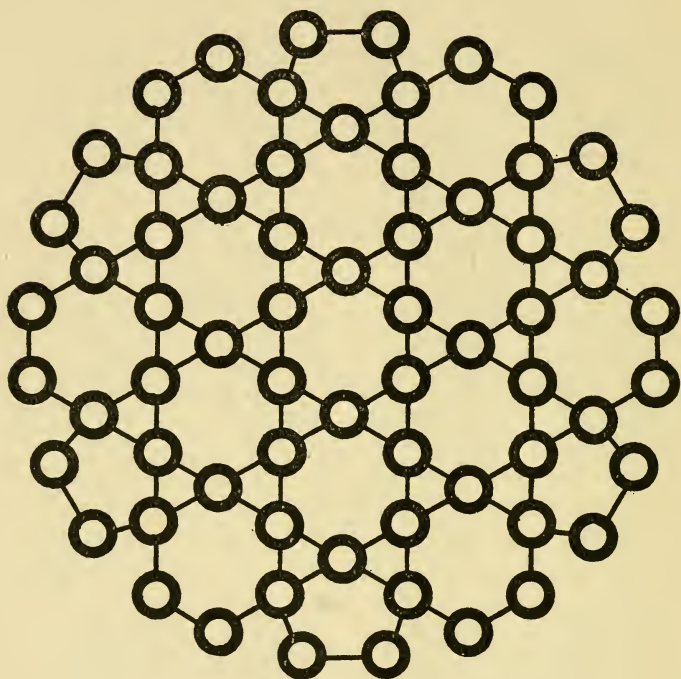


Fig. 7.

Primitive Living Organism

cron), the diameter of the organism shown in Fig. 7 should be about fifty Angstrom units (five millimicrons), which is about the size of the individual bacteriophage organisms as determined by filtration.

PERCENTAGE ELEMENTARY COMPOSITION OF PROTEINS

	C	H	N	S	O
Egg Albumin	51.5	6.76	18.1	0.96	22.7 -
Casein	53.0	7.00	15.7		22.7 -
Edestin	51.5	7.04	18.7	0.88	21.9 -
Fibrin	52.9	6.90	16.6	1.18	22.4 +
Gelatin	49.4	6.80	18.0	0.70	25.1
Gliadin	52.7	6.86	17.7	1.03	21.7 +
Hemoglobin	54.8	7.00	17.2	0.65	19.9 -

The elementary composition of a protein will also indicate to some extent the probable nature of the connecting complexes. For example, if the spirazines are connected in the manner shown in Fig. 2, then we may take as a representative portion thereof a complete triple junction and one-half of each of the three adjacent spirazines. This will have the following empirical formula:



and will have the following percentage composition:

Carbon	Hydrogen	Nitrogen	Oxygen
53.9	5.8	18.8	21.5

The only serious disagreement between these values and those obtained experimentally is in the low value for hydrogen, but that might be attributed to the fact that the individual portions of a dissolved protein are very small, so that many additional hydrogen atoms or hydroxyl groups would be required to occupy those valences which, in our continuous three-dimensional hypothetical structure would be used for connecting different portions thereof to one another.

If the spirazines are connected in the manner shown in Fig. 5, then a representative portion thereof, including one-half of each of the three adjacent spirazines with one methyl group attached to each of the alpha carbon atoms, will have the following empirical formula:



and the following percentage composition:

Carbon	Hydrogen	Nitrogen	Oxygen
50.8	7.0	19.7	22.5

It does not appear that there would be sufficient room for an ethyl group on each of the alpha carbon atoms, but if we assume that each pair of them is bridged over by a $\text{—CH}_2\text{—CH}_2\text{—}$ group, as evidenced by the molecular structures of argi-

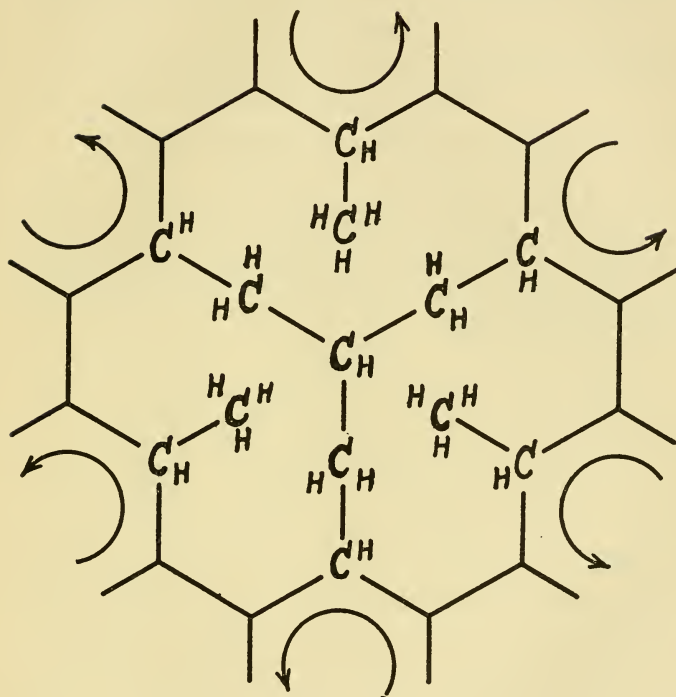
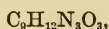


Fig. 8. A Polygonal Compartment

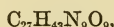
nine and ornithine, then a representative portion thereof will have the following empirical formula:



and the following percentage composition:

Carbon	Hydrogen	Nitrogen	Oxygen
51.5	5.7	20.0	22.8

Another possible configuration is that shown in Fig. 8. This is suggested by the molecular structure of leucine and will have the following empirical formula:



and the following percentage composition:

Carbon	Hydrogen	Nitrogen	Oxygen
51.0	6.7	19.8	22.5

Although no theoretical basis can be given for the complex shown in Fig. 8, yet it agrees fairly well with the percentage elementary composition of proteins as found experimentally, and also illustrates the branching at the gamma carbon atom which occurs in leucine, phenylalanine, and tyrosine. This complex can be altered in various ways by changing the connections of the carbon atoms with one another, but the percentage elementary composition will remain approximately

the same. The ratio of carbon to nitrogen as given by these configurations is slightly less than the values obtained experimentally, but that may be due to prosthetic fat or carbohydrate groups clinging to the protein structures.

If these polygonal compartments are filled with hydrocarbon complexes as suggested in Fig. 8, then we are confronted with the question of how proteins absorb water. While we were considering the structure shown in Fig. 3, we assumed that water was received directly into the hexagonal compartments. Upon further consideration, however, it seems unlikely that the absorption of water takes place in this simple manner because the absorption of water is always accompanied by considerable swelling which would not necessarily result from the mere filling of the hexagonal compartments. It appears that absorption of water and the consequent swelling can be accounted for only on the assumption that the spirazines straighten out during the process so as to produce a sort of three-dimensional network.

Sulphur occurs in the chemical structures of nearly all proteins, but is seldom present in amounts greater than two or three percent. Although several different sulphur compounds have been obtained from proteins upon hydrol-

ysis, yet they all have their sulphur in chemical combination with the beta carbon atoms of the alpha amino acids and appear to be merely different cleavage products of the same original structures. The principal sulphur-containing cleavage product is cystine, which contains a pair of sulphur atoms between two alpha amino acid groups. If we assume that all alpha amino acid groups were derived from spirazines, then we shall have to conclude that sulphur sometimes takes the place of the gamma carbon atoms in the connections between adjacent spirazines.

If we assume a sulphur content of 2.5 percent, which is more than most proteins contain, then there would be about one cystine molecule or two sulphur atoms for every eighteen spirazines as seen in transverse section.

It appears from the foregoing that living matter consists largely of a duplication of the same or similar chemical structures, and that the unit of structure cannot be much larger than one of the triple junctions shown in Fig. 2, or one of the spirazine triplets shown in Fig. 5. These various units must be quite independent of one another in their chemical behavior because they are completely separated from one another by the intermediate spirazines, and since all spirazines are

exactly alike, it appears that there must be a definite limit to the chemical complexity of living matter. We should not confuse manifoldness of structure with intrinsic chemical complexity. The number of variations which can be produced in the cross-sectional patterns of the various units of living matter by changing the connections of the spirazines with one another or by adding more spirazines thereto is enormous, and alterations of this sort in the nuclear material of the germ cells may result in all sorts of mutations during subsequent embryonic development, but the complexity is in the biological significance of the pattern as a whole and not in the chemical behavior of its component parts. Since the maximum number of atoms in the connecting complexes between two adjacent spirazines is much smaller than in many of the organic molecules which have been synthesized and studied by chemists, we may confidently expect that the gap which has heretofore existed between chemistry and biology will soon be completely bridged over, and that a satisfactory mechanistic explanation for all phases of vital activity will soon be forthcoming.

In the accompanying diagrams it has been possible to represent the chemical structure of living matter only in its statical aspect, but it should be

constantly borne in mind that the various units of living matter are not rigid crystalline structures but are plastic chemical fabrics which are almost continually in a state of metamorphosis and that it is the specific behavior of living matter and not its exact form or appearance which is carried on through successive generations. It is impossible to represent adequately on paper the various deformations of which the spirazine structure is capable, but it should be noted that besides mere flattening of the protoplasmic structures in one direction or another, there is also the possibility of longitudinal straightening out of the spirazines themselves, which can take place without the disruption of either the peptide linkings or the connecting complexes at the various junctions, so that almost every conceivable change of shape is possible with these chemical fabrics without any mutilation of the pattern which is characteristic of the species.

CELL DIVISION AND HEREDITY

Every living organism exhibits during some period of its existence the phenomenon of cell division, which may take place either by simple fission as in the case of bacteria, by budding as in the case of yeasts, by direct amitotic division of the nucleus as in the case of pathological growths or tissues of a transient nature, or by mitotic division of the chromosomes either with or without the formation of centrosomes and asters as in the case of nearly all higher plants and animals. The process is always entirely spontaneous, so that it must be the result of internal and not external forces.

It has been suggested that cell division might be due to the fact that as an object grows larger there will be a point reached where it will become physically unstable, due to the fact that its mass, which contributes to its instability, increases as the third power of its linear dimensions, whereas its surface, which by reason of its surface tension contributes to its stability, increases only as the second power of its linear dimensions. Such an explanation is inadequate because the mere presence of a large mass or volume would not cause an object to divide into fragments unless it be acted

upon by external forces, and it has never been shown that physical disturbance is necessary for cell division when the necessary food materials and environmental conditions are present.

Cell division cannot be attributed to surface tension because the effect of surface tension is always to hold a body together and never to separate it into fragments, but even if surface tension would act in the opposite direction from that in which it actually does act it would still be insufficient to account for cell division because the cohesive strength of protoplasmic fibers is far greater than any force that could possibly result from surface tension. For example, a single human hair will sustain a tension of about 40,000 dynes, whereas a filament of physiological salt solution of the same dimensions will sustain a tension of only about one dyne.

Another suggestion has been that cell division might be due to the fact that as an organism becomes larger its food requirements increase with the third power of its linear dimensions whereas the quantity of food within reach increases only as the first or second power. This explanation is also inadequate because shortage of food would only cause an organism to become under-nourished, which might retard its growth and eventually result in its death, but would not cause it to

divide. Attempts to explain cell division on the basis of food economy have been due to a confusion of the principles of phylogeny with the principles of ontogeny. It may be true that division of a large cell into smaller cells has its economic advantages and gives the species a better chance to survive, but that does not explain what causes the two halves of a cell to become separated from each other.

There are many reasons for believing that the forces which cause a cell to divide arise from within and not from without, and that a heterogeneous internal structure is necessary for this purpose. Objects such as crystals which are internally homogeneous will not generally divide spontaneously if their environment is not changed, and in those exceptional cases where spontaneous division does take place it is probably due to a certain amount of internal heterogeneity resulting from defects in the crystal structure.

The true cause of cell division seems to be intimately connected with the spirazine structure itself. In order to perpetuate the pattern which is characteristic of the species, we must assume that division always takes place in a plane perpendicular to the lengths of the spirazines; and to replace by subsequent growth what was lost by

division, we must assume that growth takes place in a direction longitudinally of the spirazines. The cohesion of such a structure in a direction longitudinally of the spirazines must be due principally to the spirazines themselves, and since the number of spirazines in the nuclear structure remains constant during growth of the individual cell, the cohesive strength thereof must also remain constant. The efforts of the spirazines to hold the structure together is opposed by the mutual repulsion of any intermediate groups that may be present, such as the side chains attached to the alpha carbon atoms or any fat or carbohydrate groups that may have been formed within the interstices of this structure. With this constantly increasing accumulation of intermediate groups it would not be difficult to account for a constantly increasing tendency to expand, and as soon as the cohesive strength of the spirazines is overcome the structure will divide into two equal halves.

The typical nucleated cell may contain several radically different kinds of self-perpetuating bodies, namely the chromosomes, the central bodies, and the plastids. Although there is a considerable amount of cooperation between these three as they pass through the successive stages

of growth and cell division, yet they are also to a large extent independent of one another. The plastids which occur in the cells of the higher plants are often freely movable in the cytoplasm and apparently have no specific structural connection with the other parts of the cell. The central bodies, which occur mostly in animal cells, are also freely movable in the cytoplasm which would not be possible if they would have any specific connection therewith, and the fact that they also sometimes occur within the nuclear membrane proves conclusively that they must be structurally independent of the other parts of the cell. The chromosomes must also be structurally separate entities, because if they would have any permanent and specific connection with the other parts of the cell they could not become twisted about one another at random so as to effect the segregation of inheritable characteristics in accordance with the laws of probability.

Although a heterogeneous internal structure is always necessary for spontaneous division, yet when the radical differences in structure and behavior between plastids, central bodies, and chromosomes are taken into consideration, it seems highly improbable that they all undergo division by the same specific method. A central body, for example, consists of a radiating cluster of twisted

protoplasmic needles called the aster, which appears to grow outwardly from a tiny central region called the centrosome. The clustering of the astral rays about common centers is in some respects similar to the arrangement of the molecules of a polar solute with the same ends toward the solution, or to the radiating clusters of needle-like crystals which are sometimes obtained by precipitation of certain substances, such as calcium sulphate. Central bodies usually occur in pairs, although four or more may occur in a single cell. A constant circulation of fluid is maintained inwardly through the astral rays and outwardly through the spaces between the rays, which is probably the means employed for gathering food material for growth. As these astral rays grow longer and become more numerous they will become more crowded in the region of the centrosome, which probably causes the entire structure to cave in and to divide into two separate centrosomes. The rays from these two daughter centrosomes will then grow and spread out in all directions, and their subsequent movement away from each other towards the opposite sides of the cell may be due to their mutual encounters. That the astral rays are rigid structures and not flexible fibers under tension is proved by the fact that

they will push inwardly the nuclear membrane whenever they encounter the latter.

The specific mode of division of the chromosomes will remain an interesting subject for further study. It was formerly thought that division of the chromosomes was brought about by the central bodies, but numerous cases have been observed where complete division of the chromosomes take place without any division of either the central bodies, the cytoplasm, or the nuclear membrane, so that it is now generally admitted that division of the chromosomes takes place spontaneously as a result of internal forces alone. In fact, there are numerous cases where the spireme thread, which subsequently forms the chromosomes, will separate completely into two lateral halves before any of the astral rays have penetrated into the nuclear region, which proves conclusively that the astral rays or central bodies could not have caused division of the chromosomes. The fact that the daughter chromosomes move away from each other most rapidly at points where they have become attached to the spindle fibers may be due to some sort of surface phenomenon, but does not prove that the original cleavage of the chromosomal thread was caused by these spindle fibers.

Since the chromosomes constitute the seat of heredity, they must consist of clusters of parallel spirazines, definitely coordinated with respect to one another. The question then immediately presents itself whether these spirazines extend along the lengths of the chromosomes, or transversely thereof. According to the spirazine hypothesis, each of the daughter chromosomes, upon cleavage of the spireme thread, must receive a complete replica of the spirazine pattern. Since the daughter chromosomes of each pair separate laterally from each other, it appears at first glance that the spirazines would have to extend transversely of the chromosomes in the direction in which the chromosomes separate from each other, and that the pattern which is characteristic of the species would have to extend in a plane perpendicular to that direction. The loss of germinal material which was occasioned by longitudinal division may then be replaced by subsequent growth in a direction transversely of the chromosomes, which may take place during the resting stage.

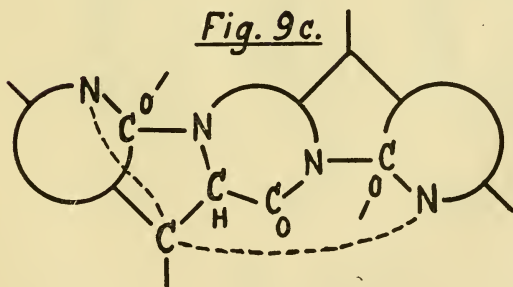
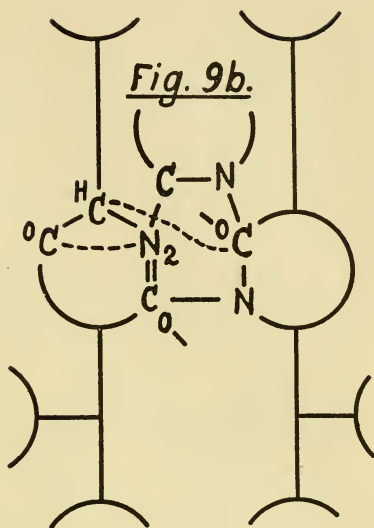
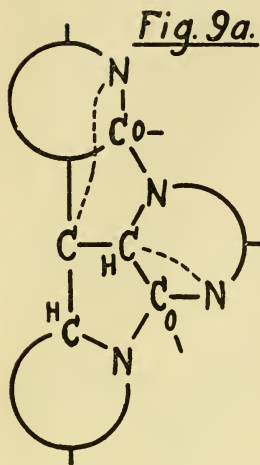
In order to explain the elongated form of the spireme thread and its ability to contract and thicken, we may assume the spirazines to be segregated into a series of separate groups which are only loosely connected with one another by the

surrounding protoplasmic network. The waste products from these groups will then constitute the chromomeres which frequently occur along the spireme thread and give to the latter a beaded appearance. Each of these groups may be very small, in fact, it may be submicroscopic, and the spireme structure that is actually observed may be only the protoplasmic envelope with which each of these groups surrounds itself. The lengthening and shortening of the spireme thread during the different stages of cell division may then involve a deformation of only this protoplasmic envelope and not of the individual spirazine clusters within it.

On the other hand, if we assume the spirazines to extend longitudinally of the chromosomes, the pattern which is characteristic of the species will be disposed in a plane transverse thereto. The two daughter chromosomes of each pair, at the time when they separate from each other, must then be assumed to possess duplicate patterns. In order to replace the loss of germinal material which was sustained by each daughter chromosome as the result of the preceding division, it appears that each of them would have to fold over on itself during the resting stage so as to produce the duplicated or bilaterally symmetrical pattern which will be necessary for the next cell division.

This can take place only during the resting stage. Although such a folding over has never been observed, yet there seems to be no other way of explaining the replacement of germinal material if the spirazines extend lengthwise of the chromosomes, and a similar process is exhibited by the pairing of homologous paternal and maternal chromosomes during synapsis.

In several cases there has been observed a delicately coiled basichromatic thread, known as the "chromonema," which occurs as a spiral winding around the spireme thread and around the chromosomes during certain stages of cell division. The chromonema is always very uniform in contour when it is first formed, but usually straightens out and thickens or collects along opposite sides just prior to longitudinal splitting of the spireme thread or prophase chromosomes. The fact that it stands out conspicuously in stained preparations does not prove, however, that it plays an important part in vital processes. Its affinity for stains may be due to nucleic acids or other purine or pyrimidine derivatives in a molecular state of dispersion which may have been formed as suggested in Fig. 9 by lateral compression of the spirazine complexes in one direction or another. Although its contents may



*Formation of Purine Derivatives
in Living Matter*

consist merely of waste material, yet its uniformly convoluted shape does indicate a spiral construction of the spireme thread or chromosomes around which it is formed, but this spiral structure should not be confused with that of the individual spirazines which are several thousand times smaller.

Ordinarily when an elongated member is wound around in the form of a spiral and is then divided longitudinally, the two halves cannot be separated

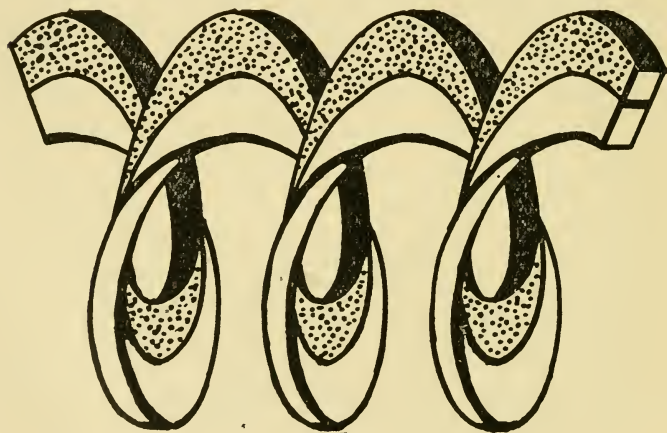


Fig. 10.

A Reversely Twisted Spiral

from each other laterally but will remain linked together. Since the spireme threads or prophase chromosomes become separated from each other completely after longitudinal splitting, they could not have been constructed in this manner, but must have had a construction similar to that shown in Fig. 10 wherein the thread itself is twisted in a direction opposite to the direction in which the coil is wound. Regardless of whether this structure remains in the form of a coil or is drawn out straight, the two halves can be completely separated from each other laterally.

In the non-sexual unicellular organisms the life cycle is complete after each cell division, but in the higher forms of life there is not only the life cycle of each individual cell, but also the larger life cycle of the organism as a whole. It is a significant fact that this larger life cycle with its extensive diversification of tissues occurs only in those organisms which possess sex.

It is usually assumed that sex is an adaptation by nature for the purpose of promoting certain phases of biological economy or for increasing the variability of the species. These assumptions, however, are not adequately supported by facts, since actual observations of the lowest organisms which exhibit conjugation, as for example the

paramecium, disclose no specialization of function on the part of the two sexes respectively, nor has it ever been shown that those unicellular organisms which reproduce by conjugation exhibit greater variability than those which reproduce asexually.

The real reason for the existence of two sexes seems to be that reduction-division followed by fertilization is the only means by which it is possible, in nature, to bring about extensive diversification of tissues. In order to produce the complex anatomical organizations of the higher plants and animals, there must occur not only a succession of cell divisions, but also a series of alterations in the chemical structures of certain of the daughter cells during early embryonic development so as to produce the different types of somatic cells which upon further division will produce the various body tissues. These alterations are the result of that extensive internal reorganization which took place during reduction-division and fertilization and seem to constitute a process of readjustment by which the embryonic somatic cells again return to a state of equilibrium. Such alterations are probably irreversible because somatic cells can never produce germ cells again, except in a few of the simplest metozoa. The natural life cycle of the somatic cells is dis-

continuous and comes to an abrupt end with the death of the individual. It is the germ cells and not the somatic cells which contain the pattern that is transmitted from generation to generation because the progenitors of the germ cells do not undergo any such irreversible alterations but only pass through a series of cell divisions and eventually produce the next generation of germ cells.

There are two different kinds of inheritance. The major anatomical characteristics by which the different species of plants and animals are distinguished from one another reappear from generation to generation and remain unaltered until there is some permanent change in the characteristics of the species. When such a change does take place it is always irreversible and not governed by Mendel's laws, from which it appears that the corresponding alterations in the spirazine pattern of the germ cells must also be irreversible. Such alterations may consist of changes in the total number of spirazines or in their connections with one another through the alpha carbon atoms. On the other hand there are certain minor characteristics, such as the colors and textures of the various body-tissues, which may change freely from generation to generation in accordance with Mendel's laws without involving any permanent change in the nature of the

species. Such minor changes take place with equal facility in either direction, from which it appears that the corresponding variations in the spirazine pattern must be completely reversible and must be confined to local changes only, such as the coupling or uncoupling of the adjacent spirazines through their carbonyl and amino groups, so as to produce that peculiar allelomorphism which is characteristic of Mendelian heredity but without producing any permanent change in the spirazine pattern as a whole.

Any feature which is transmitted by Mendelian heredity will appear either completely or not at all. It will make its appearance to exactly the same extent regardless of whether only one or both of the germ cells contain the positive or dominant characteristic. This can be explained only on the theory that the physiologically active agents in such cases are not the dominant spirazine complexes themselves but certain hormone-like substances in the dispersed or molecular state which were liberated therefrom. If either one or both of the germ cells contain the dominant characteristic, then the above-mentioned substances will be present in the protoplasm and will produce their specific effects.

MENTALITY AND SELF-CONSCIOUSNESS

The metaphysical attributes of living organisms have been given various designations such as spirit, soul, mind, intelligence, and self-consciousness. Since the present treatise deals primarily with the chemical structure of living matter, we shall consider these metaphysical attributes only in so far as they are related to protoplasmic behavior and shall designate them as "mentality" or "self-consciousness," without attempting to answer the question whether there can be associated with the physical organism a separate metaphysical entity.

Mentality and self-consciousness must be regarded as manifestations of certain functional activities of living matter and not as fluids, vibrations, or other self-contained entities because there is no satisfactory evidence to show that the mind can reach out and act beyond those chemical structures in which it originates, or that it has continuity of existence in any form whatever after the death of the individual.

It is generally thought that mentality and self-consciousness are possessed by only certain of the higher animals, but when we observe the energetic and persistent movements of some of the

simplest protozoa under the microscope it seems difficult to justify this conclusion on any sort of a rational basis. The responsiveness to stimuli and the spontaneity and arbitrariness of action upon which mentality and self-consciousness are usually predicated are exhibited not only by the nervous and muscular systems of the higher animals but also by the myoneme fibers of the unicellular organisms. For example, if a vorticella is touched the myonemes of the stalk will contract and draw the animal away from the source of irritation, just like the nerve and muscle fibers of a higher animal will respond to the touch of a hot object. The characteristic behavior of living organisms seems to be determined by the reactivity of the protoplasm itself, which always possesses substantially the same physical and chemical properties regardless of the position of the particular organism in the scale of evolution. The elaboration of protoplasmic structures into complex anatomical systems does not change the intrinsic characteristics of living matter itself, and in so far as mental attributes have their origin in protoplasmic activity they must be regarded as the common property of all forms of life.

In the most highly developed forms of life mentality manifests itself in several different ways. For example, it renders us conscious of sense per-

ceptions, it enables us to entertain thoughts and memories, and it empowers us with volition. Although artificial devices can be produced which will respond to external stimuli, retain impressions of past experience, and act spontaneously of their own accord, yet their behavior is always completely predetermined by the laws of physics and chemistry, whereas the behavior of living organisms, by virtue of their mentality and self-consciousness, is in a large measure arbitrary and self-determined.

In the vertebrate animals self-consciousness is coextensive with the central nervous system. Most of the cells of our bodies form parts of us physiologically but not mentally. In order that a cell may form part of us physiologically it is only necessary for it to be definitely coordinated in position and specifically related in function to the other cells of the body, but in order to form part of us mentally it must be coordinated with the cells of the central nervous system on a chemical scale, that is, the channels formed by the polygonal compartments must be in communication, either directly or indirectly, with certain selected channels of the cells of the central nervous system, so that electric impulses traveling through these channels will be transmitted along definite paths

to the cerebral cortex instead of being dissipated and lost in the surrounding tissues.

It is a significant fact that thoughts and memories are never transmitted through the germ cells by inheritance. If thoughts and memories were self-contained entities, such as chemical substances, then they would be carried by the protoplasmic or blood circulation to all parts of the organism and would eventually reach the germ cells and be transmitted to the next generation, whereas no trace of one's thoughts or memories has ever been inherited. It appears, therefore, that we must regard thoughts and memories not as substances but rather as manifestations of the behavior of certain chemical structures of the central nervous system which have become altered or activated by sensory impulses during the life of the individual. During embryonic life and for some time thereafter the effects of such sensory impulses are rapidly obliterated by cell division and memory is then of only short duration, but during adult life there is only very little, if any, cell division in the central nervous system so that the impressions which are then produced by sensory impulses will remain for an indefinite time.

The transmission of impulses through nerve-fibers can take place in no other way than by electrolytic conduction along the polygonal com-

partments. It cannot take place by dielectric polarization along the spirazines because the impulses would immediately pass outwardly through the side-chains and be absorbed by the surrounding tissues. Mere tubular passages containing salt solutions cannot, however, constitute the seat of self-consciousness. Neither can the seat of self-consciousness be in the cell-bodies of the sensory neurons because the cell-bodies of some of these sensory neurons are entirely separate from the nerve-fibers and can be completely removed without interfering with the passage of afferent impulses. Although the cell-bodies of the motor neurons are usually arranged directly in the paths of the nerve-fibers, yet there is no indication that they take any active part in the generation of impulses and probably serve only as nutrient centers.

The only remaining structures in which self-consciousness could originate are the sensory and motor end-organs and the synapses, including the dendritic fibrils of the cerebral cortex. These terminal arborizations are so finely divided that many of them are undoubtedly beyond the range of microscopic vision, and the terminal knobs or plates of sensory and motor nerves which stand out so prominently in stained preparations under the microscope are probably only coagulation-

products which take no active part in the generation of impulses but which contain the delicate fibril-endings hidden within them.

Whenever a nerve-fiber traverses a considerable distance it is covered by a protecting neurilemma, and in some cases also by an inner medullary sheath which prevents the diffusion of ions through the side-walls of the axis-cylinder. Near the end-organs these investments terminate abruptly or leave the axis-cylinder, which immediately arborizes into a number of delicate terminals surrounded by irregular accumulations of coagulation-products, from which it may be assumed that vigorous metabolism is taking place in these regions.

The transmission of nerve-impulses is peculiar in that it always takes place in only one direction, although the electrical conductivity of nerve-fibers is the same in both directions. It appears, therefore, that the same end-organs which generate an impulse must also determine the direction thereof and that the direction is always the same for the same end-organ, unless we make the highly improbable assumption that the end-organs generate alternating impulses which are rectified while passing through the synapses. Although it is quite possible that the synapses may possess only unidirectional conductivity, yet without a differ-

ence of potential there would be no movement of ions through them.

Since electrically charged ions of the same sign cannot accumulate in considerable numbers, it appears that the end-organs must be permeable to such ions so that the positive and negative ions will be able to migrate through them in opposite directions when an impulse is created. In order to produce such an impulse, nothing more is necessary than a change in the relative permeability of the end-organs to positive and negative ions, the necessary energy of motion being already possessed by the ions themselves. Although it may be true that the nerves undergo a certain amount of metabolism during activity, yet it seems more reasonable to regard this metabolism as the result, rather than the cause of nerve-activity. It is inconceivable how any sort of metabolic activity could produce differences of potential in different parts of an organism unless the surrounding physical and chemical structures are properly organized for such a purpose, and if these structures are in themselves adequate to produce such differences of potential then we do not need to invoke metabolism. The metabolism that does occur may be due to wear and tear of the end-organs during activity and to the efforts of the spirazines to repair the worn structures.

Whether migration of ions can take place through the interstices in the sides of the polygonal compartments or only through their open ends cannot be definitely answered, but it is not unlikely that it can take place either way. Spirazines being formed like coiled springs, a bundle of them may be drawn out lengthwise whereupon the openings in the sides may become about as large as the openings through the ends, which will be amply sufficient to permit the migration of ions therethrough. Such openings will not, however, be large enough to permit the free flow of the solution therethrough. This will be apparent when it is considered that a single polygonal compartment measures only about ten Angstrom units (10×10^{-8} cm) across, and that small molecules or ions measure about two or three Angstrom units across.

Whenever migration of ions takes place through openings as narrow as these, the movements of the ions will be strongly affected by the electric fields of the atoms forming the margins of the openings. The distances through which these electric fields can act effectively can be calculated from Van der Waal's equation and will be found to be just about sufficient to span the distance from the periphery of one of the polygonal compartments to its center. Since the spirazines

themselves are polar structures, the surrounding electric field will also be polarized, and any polarization of the electric fields around the openings at the ends of the polygonal compartments will result in selective and unequal diffusion of the ions therethrough. A similar selective and unequal diffusion may also take place through the interstices in the sides of the terminal fibrils. As long as conditions are in equilibrium, a certain difference of potential will be established and nothing further will happen; but upon disturbing or irritating the fibrils, as by applying pressure, heat, or electricity, the dimensions or electrical conditions of these interstices may change, and consequently also the relative rates of diffusion of positive and negative ions therethrough which will produce the electric impulses to be propagated along the nerve-fibers.

When a sensory impulse is produced the energy is not always transmitted only to the motor nerves but a portion of it may pass through the spinal cord or through the cranial nerves to the brain and finally to the supra-granular or molecular layer of the cerebral cortex which is generally thought to be the seat of self-consciousness. It does not seem likely that sense-perceptions of short duration can cause the formation in the cerebral cortex of new fibrils because some sense-

perceptions last only a small fraction of a second but nevertheless make a permanent impression on our memory, whereas to build up nerve fibrils of any length by endwise growth of the spirazines would require a considerable period of time. The immediate effects of such sense perceptions on the cerebral cortex must therefore consist of alterations in the chemical structures of the fibrils already present and not in the formation of new fibrils. Since impulses which enter the brain can only be in the form of electric currents, it is not unlikely that they may effect some sort of activation of the associative fibrils, as a result of which the latter may continue to generate similar potentials in the future. Thus, when an electric impulse from a sense-perception enters the cerebral cortex the ions may force their way through the dormant chemical structures which form the walls of the fibrils of the gray matter and leave open but restricted passageways in their wake which may permit the subsequent migration of similar ions in the same direction. Recurrent impulses similar to those of the original sense-impression may therefore be generated and will manifest themselves as thought or memory, unless they find an outlet through the motor nerves in which case they will manifest themselves as acts of volition.

Whether the exercise of free will or volition involves any violation of the fundamental principles of physics and chemistry is a question on which there is much difference of opinion. The existence of free will is being made known to us directly through our self-consciousness, and it would be very dogmatic and unscientific for us to reject the testimony of our self-consciousness in so far as it furnishes us with a basis for our belief in free will, but yet to accept it in so far as it informs us of the operation of the laws of nature.

According to the classical conception of natural laws the behavior of every physico-chemical system is completely predetermined, whereas the exercise of free will introduces factors which are arbitrary and self-determined. Since there cannot be two independent systems of governing forces acting in the same place and at the same time, we must either regard free will as a delusion, or we must assume that living matter does not come under the domain of those natural laws which govern physico-chemical systems.

The classical principles of physics and chemistry, which seem to signify predetermination to the exclusion of free will, were derived from experiments upon isolated physico-chemical systems and deal only with the effects of simple elemen-

tary forces or with the combined or average effects of large numbers of atoms or molecules. There is no artificial device known which will respond to the specific behaviors of the individual atoms or other elementary particles of matter, and we cannot extend the laws of physics and chemistry by analogy into realms where conditions are not the same as those under which such laws were derived. It is only through the medium of living matter that the behaviors of the individual atoms can manifest themselves. In chemically organized structures of this sort some of the atoms may occupy positions of advantage so that their specific individual behaviors may become amplified sufficiently to effect the excitation of nerve or protoplasmic fibers, and it is this amplification of the activities of individual atoms which establishes the condition of self-consciousness. Artificial devices can never possess self-consciousness because their behaviors are always completely predetermined by the principles of geometry and statistical mechanics which form the basis of all the laws of physics and chemistry. The behaviors of the individual atoms, however, are not subject to the principles of statistical mechanics, and the effects of geometric relationships are being continually obliterated by the con-

stantly changing electrical conditions in the regions between the adjacent atoms.

The responsiveness of living matter to the activities of individual atoms can be readily demonstrated by certain optical experiments. After determining the maximum distance from which a small white object can be seen by the light from a candle-flame, and knowing the size of the pupil of the eye, we can calculate the minimum intensity of light to which the eye is sensitive. Since the radiant energy from one candle-power which falls within the limits of the visible spectrum amounts to about 190,000 ergs per second, the minimum amount of light-energy per one-fifteenth of a second to which the eye is sensitive can then be calculated. It will be found to be not much greater than 10^{-12} erg, which is approximately the amount of energy required to eject one electron from an atom.

All natural processes which do not involve the activities of living matter may be classified as reversible and irreversible. Reversible processes are those which are governed by the primary laws of nature. They will proceed equally well in either direction and will not change the entropy of the system. Irreversible processes are those which are governed by the second law of thermody-

namics. They appear to proceed of their own accord in only that direction which involves an increase of entropy. It has been shown by Boltzmann, however, that the direction in which irreversible processes take place is determined by the principles of statistical mechanics and that the direction is always such as will involve a change from a less probable to a more probable state. This concept of entropy has been further explained by G. N. Lewis, who has shown that in purely physico-chemical processes there is really no preference of direction, and that the apparent increase of entropy means merely loss of information. The entropy concept has therefore a purely subjective origin and cannot exist of its own right.

It should therefore not be surprising when we find that the chemical structure of living matter recognizes no second law of thermodynamics. In chemically organized structures of this sort the orderly arrangement of the atoms along the sides of the polygonal compartments will tend to sort out rather than mix up the molecules or ions within them. The passages which lead into or out of these polygonal compartments being of the order of molecular dimensions, it is conceivable that the surrounding chemical structures may be so constituted that they will behave like Maxwell's demons and close or open these passages accord-

ing to whether the approaching molecules or ions are of one kind or another. This will result in a sorting out of different kinds of molecules or ions from one another so as to build up osmotic or hydrostatic pressures or electric potentials. Processes such as these will take place irrespective of the second law of thermodynamics because the energy which is thus rendered available will not have been obtained entirely from the oxidation of food material but partly from the heat of the surroundings.

Vital energy of this sort should not be confused with vital force, for the two have nothing in common. The principle of vital energy is entirely consistent with the laws of nature and supplements rather than contradicts them, whereas the doctrine of vital force assumes the existence of some mysterious power which is supposed to act in contravention to the laws of physics and chemistry to control such processes as metabolism, growth, and reproduction. Vital energy is within the realm of the comprehensible and the possible existence of such a form of energy has been suggested by physicists long before the conception of the spirazine hypothesis, whereas vital force is supposed to be something which is incomprehensible to the human mind, and the existence of which would be contrary to all the principles of science.

THE NATURE OF PHYSICAL REALITY

The origin of mental processes is so deep-seated in the elementary structure of living matter that there should exist the closest congruity between the conclusions of the mind and the underlying principles of physics and chemistry. The activities of natural forces have been found, in general, to proceed consistently with the principles of mathematics, and it is a significant fact that mathematical truths are also the only truths which are self-evident to the human mind. There are, however, a few peculiar cases where the conclusions of the mind have appeared to be contrary to actual facts, or where the mind seems to have been incapable of forming a correct conception of the true nature of physical reality. Foremost among such cases are the imaginary even roots of negative numbers, the paradoxical special principle of relativity which states that the velocity of light is independent of the relative velocity of observer and source, the supposed curvature of space, and the ultimate nature of matter and electricity.

The existence of imaginary quantities in algebra is the result of certain conventionalities which have been adopted for the solution of equations,

and does not indicate the existence of anything mysterious or incomprehensible in the ultimate make-up of the universe. Algebraic symbols are of significance only in so far as they represent magnitudes which can be measured, and all measurements have space and time as their background. It is generally conceded that space is perfectly symmetrical, and it has recently been shown by G. N. Lewis that time is also symmetrical with respect to past and future. It should therefore be entirely possible, and would appear to be perfectly logical, to represent the phenomena of nature by a system of mathematics which is symmetrical in the use of positive and negative signs. Such a system would contain no imaginary quantities, but would not lend itself as readily for the solution of equations as our present system.

The special principle of relativity which comprises the incomprehensible proposition that the velocity of light is independent of the relative velocity of observer and source has been proposed in an effort to explain the negative result of the Michelson-Morley experiment. It has been shown, however, that the results of this experiment can be completely accounted for if we assume that the light waves, after leaving a source which moves along with uniform velocity, re-

main concentric with the source. The special principle of relativity therefore requires something more than the Michelson-Morley experiment for the establishment of its validity. Efforts have been made to prove this principle by experiments upon light radiation from a rapidly moving stream of canal rays and from the approaching and receding limbs of the sun's corona. It has been contended that since such radiation exhibits the Doppler effect it cannot partake of the motion of the source in the manner suggested, but it does not appear that such a conclusion necessarily follows because the Doppler effect will be exhibited whenever there is relative movement between the source of light and the observer. Efforts have also been made to prove the special principle of relativity by observations upon double stars, but the very fact that the distant realms of the universe have to be searched in order to find evidence for the support of this principle should render us cautious. It does not appear that there is a single experimental fact in support of the special principle of relativity which cannot be explained more readily in other ways, and since this principle is in itself incomprehensible to the human mind and leads to all sorts of paradoxical conclusions it is difficult to see any justification for its acceptance.

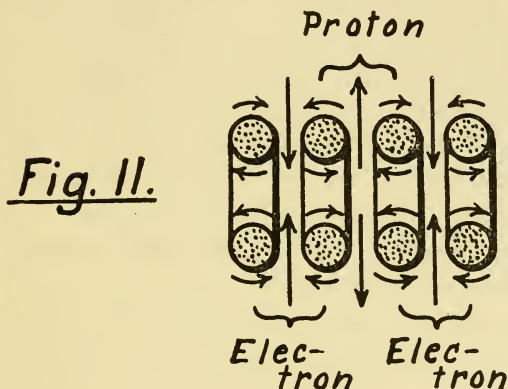
The intrinsic nature of matter and electricity has also been thought to be incomprehensible to the human mind. The specific properties of the various kinds of matter are, however, being rapidly explained on the basis of atomic and molecular structures. Perhaps the most difficult phase of this subject is the problem of accounting for the two kinds of electricity of which all matter is composed. Any theory of matter and electricity that is to deserve serious consideration must explain, first of all, the self-sustaining ability of atoms, protons, and electrons. The only form of motion which is dynamically self-sustaining is vortex motion, and since electricity is closely related to matter both in constitution and behavior, it would not be unreasonable to assume that electrical vortices are also self-sustaining. It has been suggested in the early days of the atomic theory that the ultimate particles of matter and electricity might consist of electrical vortex rings, but the apparent inability of the vortex theory to account for two kinds of electricity has prevented further development of this theory. It appears, however, that the various possibilities of vortex motion have not yet been fully investigated. Besides simple vortex rings there is also the possibility of pairs of vortex rings, which may be arranged with their adjacent peripheral portions

moving either inwardly, outwardly, or in opposite directions. Since each of these forms is intrinsically different from any of the others, it appears that we have ample material here with which to account for the two kinds of electricity.

If double vortex rings exist, then it appears that single vortex rings cannot exist permanently for any length of time. In order to form a stable system, the two halves of a double vortex ring would have to attract each other and resist separation; and if the individual vortex rings do attract one another they would immediately combine to form double rings and could not exist singly for any length of time. It further appears that double rings with their adjacent sides moving in opposite directions could not exist because the abrupt transition from movement in one direction to movement in the opposite direction would cause repulsion between them. The only remaining possibilities are therefore double rings with their adjacent sides moving either outwardly or inwardly, and these may constitute protons and electrons, respectively. If their adjacent sides move inwardly, then the inward flux would take place along the entire equatorial plane and the outward flux only at the poles; whereas if the adjacent sides move outwardly, then the reverse conditions would exist. This may be the reason

why protons are about 1847 times heavier than electrons.

If electrical vortices always attract each other when they have closely adjacent surfaces moving in the same direction, then it appears that a series of them arranged as shown in Fig. 11 should form



Diagrammatic representation of nuclear vortex structure.

a stable system. This may be the arrangement which exists within the nuclei of the atoms. Such a series may be considered as having been built up of either protons or electrons. When a number of vortex rings are arranged in such a series they will probably all assume the same diameter because the immediate environment of each ring

will be the same as that of any other ring. If we assume that the proton is smaller than the electron, then any particular pair of rings which by itself would form a proton would tend to increase in diameter, whereas any particular pair which by itself would form an electron would tend to decrease in diameter. The final diameter should therefore be somewhere between that of a free proton and that of a free electron. This is exactly what has been established experimentally, since it has been found that the hydrogen atom, which contains only one proton, has an atomic weight of 1.008 whereas the helium atom, which contains four protons, has an atomic weight of just 4.00 and not 4.032.

The electrostatic attraction between unlike charges and the repulsion between like charges is probably due to the fact that at considerable distances the equatorial flux dominates over the polar flux so that the charge as a whole will establish either a divergence or a convergence, depending on whether it is a proton or an electron. If both charges are of the same sign, then the lines of force in the regions between them will be oppositely directed so as to cause repulsion; but as the two charges are brought more closely together the region of repulsion will become smaller so that the force of repulsion will gradually disappear and leave the two charges firmly united in

the form in which they probably exist in the nuclei of the atoms. If the two charges are of opposite sign, then the outward equatorial flux from the proton will be continuous with the inward equatorial flux of the electron, and the outward polar flux from the electron will be continuous with the inward polar flux of the proton, so as to form a closed circuit which will link the proton with the electron in such a manner as to cause attraction; but as the two are brought more closely together the repulsion effect of their oppositely moving adjacent surfaces will become more pronounced, so that a point will be reached where this force of repulsion will be equal to the force of attraction, which appears to explain why the electrons in the outer regions of the atoms do not coalesce with the protons of the nucleus.

Another attempt to enter into the realm of the incomprehensible in order to find the true explanation of a natural phenomenon has been the recent suggestion that gravitation may be due to a curvature of space and that it may therefore constitute something fundamentally different from the other forces of nature. One of the main reasons which have been advanced in support of this theory is the fact that gravitation cannot be screened in the same manner as electricity and magnetism. The apparent screening of electric and magnetic

forces is, however, due to neutralization by induced electric charges or magnetic poles of opposite sign. It is readily conceivable that the same force may behave like electricity or magnetism at comparatively short distances, but like gravitation at much greater distances, and that the true explanation for all of these forces may be found in the properties of electrical vortices.

It appears from the foregoing that there is still such an abundance of unexplored subject-matter in the realm of the comprehensible that it is altogether too soon to invoke the supposed fourth dimension or other imaginary realms or supernatural agencies in our efforts to explain natural phenomena. Although the reliability of our mental processes has lately fallen somewhat into disrepute as the result of recent non-Euclidean mathematical adventures, yet we may confidently expect that after the futility of these recent adventures is being realized there will be a return to rational concepts. It is human nature to attribute to supernatural causation anything which cannot be understood or explained in the light of contemporary scientific knowledge; but if the boundaries of science will continue to expand at the rate at which they have been expanding during recent years, then it will be only a question of time until the supposed realm of supernatural causation will have vanished from existence.

THE CAUSE OF PURPOSIVENESS

(1932 Supplement)

Living matter differs from dead matter not so much in its chemical constitution as in its behavior. Dead matter, regardless of its origin, is always indifferent in its behavior, whereas living matter always behaves as though it had a definite purpose. The self-coordinating, self-controlling, and self-directing ability of living matter in all its forms and activities is too pronounced to escape attention, and cannot be explained by any fortuitous juxtaposition of molecules. If two masses of dead protein material are brought into contact with each other, neither will have any advantage over the other and both will remain inert. However, if one of these masses be brought near a living cell, it will be gradually digested and assimilated by the latter. Now, if this were an ordinary chemical reaction, then the chemical affinity of the living cell for the amino acid radicles of the dead protein material would be satisfied after the first layer of radicles had been assimilated, but actually the cell is just as hungry afterwards as it was before.

There is only one artificial process which shows a similar behavior, and that is electrolytic depo-

sition. No matter how many ions have already been deposited electrolytically, there is a constant effort to deposit more, even from dilute solutions. The assimilation of food materials by living cells can therefore be explained if it can be shown that such cells can generate electric potentials. It has already been shown that living matter consists of a delicate chemical fabric in which the interstices are of molecular dimensions, and it is entirely possible that the interstices may be of just such a size as to permit the small positive hydrogen ions to escape, but not the larger negative acid ions. The latter will therefore accumulate within the protoplasmic fabric so as to build up a negative electric potential.

This negatively electrified protoplasmic fabric will attract and form peptide linkings with the exposed amino acid radicles of any mass of dead protein material in its immediate neighborhood, and when the latter again breaks away it will leave the exposed amino acid groups behind to form parts of the living structure. Any amino acid radicle which is being assimilated will arrange itself with the amino group directed inwardly towards the protoplasmic fabric, and with the carboxyl group directed outwardly. Active assimilation therefore takes places only at the

carboxyl ends of the spirazines. The amino ends are probably in chemical combination with the phosphoric acid radicles of the nucleotides in the nuclear regions of the cells. Since spirazines are so constituted that their external chemical configurations are not changed by the addition of amino acid radicles thereto, this proces of assimilation should be able to repeat itself any number of times. The theory that anabolism is under positive electric control from the central or nuclear regions will also account for the inherent tendency of every living organism to complete its structure, to preserve its integrity, and to maintain itself in a definite stationary state regardless of changes of environment.

Some of the negative ions within the growing protoplasmic structures may become neutralized or lost, but these are probably replenished from the opposite ends of the spirazine clusters. It has frequently been observed that a constant unidirectional circulation of fluid takes place through protoplasmic structures, and if the passageways through such structures are of the order of molecular dimensions then the molecules and ions in their immediate neighborhood may become sorted out by the electric fields of the surrounding spirazines so as to effect a separation of acid from alkaline substances. With crude arti-

ficial devices this cannot be accomplished, but in a chemically organized structure like living matter the atoms which form the margins of the passageways may behave like Maxwell's demons so as to close or open such passageways according to whether the approaching molecules or ions are of one sort or another.

The same result may also be brought about by chemical reactions. For example, a carbohydrate molecule may attach itself to one end of a spirazine cluster in such a position that upon becoming oxidized it will send the carbonic acid molecules into the tiny passageways towards the opposite end of the cluster.

In the ideal case just considered there resulted only the building up of a simple fibrous or cylindrical structure, but in cases where the clusters of spirazines are arranged and interconnected according to more complex patterns, new morphogenetic activities will appear and new behaviors will be manifested, but the underlying principles will remain the same. Since each individual living cell, just like every vertebrate animal, is under substantially the same system of internal electric control, we should expect to find in all cases the same coordination of action, the same governing motives, and the same purposive behavior in the interests of the organism.